AMYGDALA $z \mapsto z^2+c$

A Newsletter of fractals & $\mathcal{M}$ (the Mandelbrot set)
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SECOND SERIES

This issue #11 of **Amygdala** marks the beginning of the second series of newsletters.

For those of you who have the color slide supplement, the four slides enclosed herewith begin the second series of slides. I expect to include four slides with each issue of the second series, so you should get all 24 slides by issue #16.

"THE SCIENCE OF FRACTAL IMAGES"

—Edited by H.-O. Peitgen and Dietmar Saupe

328 pp. 142 illus. in 277 parts (39 color plates); hardcover $34.00.

From the Springer Newsletter, Mathematics 2 / 1988:

The Science of Fractal Images is a new book discussing fractals from a computer graphic viewpoint. It is based on a SIGGRAPH '87 course given by these five recognized leaders in the field.

- **Michael F. Barnsley:** Fractal Modelling of Real World Images
- **Robert L. Devaney:** Fractal Patterns Arising in Chaotic Dynamics
- **Heinz-Otto Peitgen:** Fantastic Deterministic Fractals
- **Dietmar Saupe:** Algorithms for Random Fractals
- **Richard F. Voss:** Fractals in Nature: Characterization and Measurement

The foreword is written by **Benoit B. Mandelbrot,** whose fractal geometry has served as a mathematical model for many of the complex forms and patterns in nature and the sciences. The forward includes his comments on the computer graphic history of fractals.

The Appendix includes four further contributions:

- **Benoit B. Mandelbrot** shares his new ideas to create random fractals, which are directed towards the simulation of landscapes, including mountains and rivers.
- **Michael McGuire,** who works in the tradition of Ansel Adams, presents a collection of his magnificent photographs.
- **Dietmar Saupe** provides a short introduction to rewriting systems, which are used for the modelling of branching patterns of plants and the drawing of classic fractal curves.
- **Yuval Fisher** introduces the fundamentals of a new, extremely efficient algorithm for the Mandelbrot set.

This is a how-to book that bridges the gap between mathematical foundations of fractal geometry and the computer generation of fractal images. This exciting new field is making important contributions in areas such as advertising, publishing, communications, and image processing. Anyone wishing to see more than beautiful pictures will find state-of-the-art algorithms and many pseudo-codes previously known only to specialists.

Available August 1988, **The Science of Fractal Images** will open the door to further exploration of this fascinating subject.

RS: The Math editor at Springer told me that she expects **SOFI** to be released on July 22. **Amygdala** will be selling copies for $34 postpaid (or whatever the price turns out to be), and will mail copies Book Rate as soon as we get them. Priority mail will get it to you sooner, but will cost you an extra $4.75.

THE SLIDES

Those subscribing to the color slide supplement now have the first four slides of the current series of 24 slides. This series is, I think, at least equal in splendor to the first 25.

178: John Dewey Jones. Clown face in beige, yellow & gray.

180: John Dewey Jones. "The Mandelbrot set turned inside out. I've replaced z_0 with $1/z_0$ in $z_n \leftarrow z_{n-1}^2 + z_0$. Dwell limit 64, looking at the box with opposite vertices -3-2i... 5+2i. Two versions are given in this slide and #183, this one softened-up by removal of the outer layers to give a sea-anemone-like blob. (I could quite see how both of these might be unappealing, particularly if viewed early in the morning.)"

183: John Dewey Jones. "Another version of #180: a heavily bloodshot 'Tequila Sunrise'."

601: Charles Fitch. "Buddha's Brain. A beautiful and intriguing rendering of the inside — as well as the outside — of M."

Here is a correction for slide **#202**, distributed with Amy #8, and described therein as a "Lovely lacy white Julia set on cobalt ground. Fascinating in spite of (or because of?) the minimal coloring." John Dewey Jones writes:

Note that image #202 from Amy #8 is a 'difference set': each point is colored according to the absolute value of the difference between the dwell at that point for the Julia set generated by (-0.745+0.11i) and the dwell for the Julia set generated by a second point displaced by a small amount: (0.00005+0.00005i). The portion of the plane involved is (-1.7-1.5i) to (1.7+1.5i). It is this technique that gives #202 its minimal appearance.

PRICE INCREASE

Prices for subscriptions to the newsletter and the slide supplement will increase on August 1 as follows:

CURRENT SUBSCRIPTIONS	
Newsletter, issues #11-20:	
US, Canada, Mexico:	$25.00
Elsewhere (Air Mail):	$30.00
Newsletter #11-20 + Color Slides #25-49:	
US, Canada, Mexico:	$45.00
Elsewhere (Air Mail):	$50.00
BACK ISSUES	
Newsletter, issues #1-10:	
US, Canada, Mexico:	$25.00
Elsewhere (Air Mail):	$30.00
Color Slides #1-25:	
US, Canada, Mexico:	$20.00
Elsewhere (Air Mail):	$25.00

Orders received prior to August 1 will not be affected by the price increase.

BULK MAIL AND YOU

The last few issues have been sent U.S. mail, third class, bulk rate, which means that if you move, and do not send a change of address, you risk your issues going amiss, since the U.S. Postal Service will not forward bulk mail.

I can't shoulder the expense of replacing issues so lost, via first class mail. That will cost you $3.00 per issue. Be warned!

MACINTOSH II MANDELBROT PROGRAMS

—Ken Philip

*RS: Ken's review is the result of considerable careful study and evaluation, and should be of great interest to many subscribers. Some of you may be taken aback by the amount of space devoted to a subject which seems to be of little interest to you, since you don't own a Mac II. Pause ye, and consider that this excellent piece of work may serve as a model for another reviewer, who, inspired by its example may later provide a review of equal excellence for software on the machine of **your** choice.*

Over the past 8 months since acquiring a (long-awaited) Macintosh II, I have obtained seven color Mandelbrot Set programs for the machine—all public domain or shareware, and all utilizing the 68881 math chip for added computational speed. I thought it would be useful for other Macintosh II owners with an interest in fractals to have some information on these programs, so here is a review. The programs are:

- **Mandel8**, by Stephen Eubank (earlier version was called **Mandel881**).
- **MandelColor**, by Robert Woodhead. Version 5.5.
- **Megabrot**, by David Van Brink (© MegaGraphics 1987). Version 0.8.
- **Mandelbrot Microscope**, by Martin Sandberg & William Hembree (Crystal Canyon Computing).
- **Ani–Mandel**, by Mark Lankton. Version 1.2.
- **MandelZot**, by Dave Platt (Coherent Thought, Inc.). Version 0.9.
- **Mandelbrot**, by Ben Haller. (Applesauce Designs) Version 2.7.

The version numbers are included (where given) since all of these are under development. If you have a later version than given above, you may find additional capabilities. Any negative comments in this review apply only to the versions above, or earlier versions if specified.

I have spent some time experimenting with all of these programs. Most of them have at least one unique and useful feature, and each of them is either incomplete or in some way falls short of what an ideal Mandelbrot program should be. One really needs at least a couple of them in order to explore the Mandelbrot Set fully.

More than half of these programs do not save their images. Since computation times can run to half an hour or more at high dwell levels, it is inconvenient to have to recompute a screen each time you want to view some detail of the Set. I strongly recommend that anyone planning to make use of these programs obtain a copy of 'Colorizer', from Palomar Software, or the FKEY 'ScreenDump][' by Mike Whittingham. These utilities will let you save a color screen image to disk as well as print a color screen to an ImageWriter II.

One warning is necessary here. All of these programs are memory hogs, and there is no guarantee that they will run on a one–megabyte machine. In fact, ANI–MANDEL carries an explicit notice not to try it unless you have at least two megabytes. Since my Mac II has 2 MB of RAM, I was unable to test these programs for their performance with only one megabyte—but don't be surprised if you find that one megabyte is not quite enough for some of them.

A few comments should be made on the inherent capabilities of the Macintosh II as a Mandelbrot Set engine so we can see how well the programs utilize the hardware. A Mac II, with the standard Apple color monitor driven by the standard video card with extra RAM installed for an 8–bit display, is capable of displaying 256 simultaneous colors on a 640x480–pixel screen. The math chip (68881) in conjunction with the 16MHz 68020 CPU can run floating–point math at 0.1 megaflops (1 MFLOP = one million floating–point operations per second). The math package uses 80 bits, of which 63 are reserved for the mantissa, so truncation errors should not set in until about the 19th decimal place. That should allow a magnification of almost 5 quadrillion diameters (on a 640–pixel wide screen) before any deterioration of the image from math truncation starts to take effect. (Large–screen monitors with a higher pixel count will show truncation effects at slightly lower magnifications.) Usable magnifications with slight truncation effects should extend to over 10 quadrillion diameters. To give an example of the computing speed in practice, the program ANI–MANDEL takes 3.5 minutes to compute and display a full–screen view of the entire set with a side length of 3 (**Re** from -2.25 to +0.75, **Im** from -1.125 to +1.125) and a maximum dwell of 100. Fixed point math can do this faster—but a 32–bit fixed–point computation has a maximum magnification of about 8 million diameters, rather than 10 quadrillion!

Now let's examine each program in detail. Note that some terms used in the description of individual programs are explained in the 'Discussion of Features' after the table that summarizes the programs. Note also that all these programs can display the image line by line (or in some cases pixel by pixel) as it is being drawn—a useful feature which saves time, since it allows you to abort an unsatisfactory plot without having to complete all the computations first.

Mandel8

MANDEL8 is a straightforward program which images the Mandelbrot Set in a 'contrast' CLUT in a nearly standard Macintosh window (growable, and scrollable with the arrows but not with the thumb). It computes at about half the speed of the other programs. Selection of the next plot is done by dragging a rectangle with the mouse—but unless that rectangle has the same aspect ratio as the window the magnification factor will be different for the real and imaginary axes. After a long series of plots at increasing magnification there will inevitably be some magnification difference between the two axes. An option–drag will scale the image down rather than up, so it is possible to back out of an uninteresting plot.

The screen can be saved as a PICT image, but not opened by MANDEL8. ATG Paint can open the file, but Pixel Paint and Colorizer cannot.

Truncation limits the magnification to approximately 100 million diameters—a precise measurement was not possible because the coordinate reporting routine is good to 5 decimal places only.

Scrolling in the window is somewhat odd. The 'thumbs' are shown, but they do not work. The scroll arrows *do* work, but the screen will be properly painted only if you scroll one click at a time, waiting for that line to be painted before clicking again.

Multiple windows may be put up simultaneously.

I find the colors in MANDEL8 rather uninteresting. An older version (MANDEL881) had more attractive colors, but could not refresh its screen or save files in any format.

One final feature: an item under the Apple menu puts up a box showing the computing speed in floating–point operations per second.

MandelColor

Within its magnification limits, this is an excellent program which yields attractive images. Selection is done either by dragging and then selecting the 'New' option in the File menu, in which case the corner coordinates of the selected region are automatically posted to the text entry fields in the dialog box, or by going directly to the dialog box and typing the desired coordinates. The aspect ratio is forced to be correct, so you may see more than you had in the selection region if you used an aspect ratio different from that of the plotting window. Note that MANDELCOLOR assumes that positive values of **i** are negative, which makes the imaginary corner coordinate fields counterintuitive.

The dialog box also lets you set the size of the plotting window in pixels, select a number of colors between 4 and 240, set the escape radius (default = 100) to any value from 10 to 1000, and select a gray-scale (for B&W monitors) or a 'contrast' CLUT. The default CLUT is a 'smooth' rainbow–type progression of hues. A check box labelled 'False Perspective' produces an odd–looking screen that gives a vague impression that you are viewing the Set from an angle, but I do not care for the resulting image.

The program will refuse to accept pairs of corner coordinates for either axis that do not differ by one in the last decimal place, which puts a hard limit of 30 billion diameters on the magnification.

One delightful feature of MANDELCOLOR is CLUT animation. Each color in the lookup table is replaced by the adjacent color, at high speed—and the result is that the color bands move rapidly into the Set producing an almost hypnotic display. Unfortunately, when you stop the animation the colors reset to their original values, which makes this feature useless for photography.

The program will save files, and reopen them as working files—an immensely valuable feature. There is also a routine, which I have not tested owing to lack of disk space, for automatically zooming in on (or out from) a selected region and saving files as it goes. This routine may be used to create motion picture sequences if you photograph (or frame grab to video) the resulting images.

Screens may be saved to the Clipboard in PICT format, from whence they may be exported to other programs.

Finally, MANDELCOLOR will run under MultiFinder in background mode, which allows you to compute Mandelbrot images while word processing or doing some other task. I did, however, find some anomalous behavior about window–handling while running in background mode—you will find the screen works better when backgrounding if you leave a small window with the original plot as the front window, and let the large window with the current plot be a back window. If the current window is made the *front* window, the contents of the smaller original window will be tiled across the front window as the plot goes on. This peculiar behavior happens only when MANDELCOLOR is running as a background task.

The major defects of MANDELCOLOR are the magnification limit (which is under the 68881 limit by a factor of 1 million), and the fact that the maximum dwell is equal to the number of colors chosen and thus cannot exceed 240. That is simply not high enough!

However, within the magnification range it can handle, MANDELCOLOR produces very attractive images, either in smooth or contrast CLUTs—and its full–screen capability and file saving make it a good program for people who intend to produce color slides.

Megabrot

MEGABROT appears to be the program that the Megagraphics company provided to work with their Megabrot card, which runs Mandelbrot Set calculations over 100 times faster than the 68881 chip can do them. It will also work on a Macintosh II without that card.

This is a program with a number of interesting features, but the fact that it cannot refresh its screen (even after its own dialog boxes), and its absurdly low magnification limit of 8 million diameters even in 80–bit floating–point mode, make it less useful than its other features might indicate. Also, the fixed–size display is not optimum for photography.

MEGABROT plots in a fixed 400x400–pixel window, and thus cannot take advantage of large–screen displays. Selection is by dragging or by typing into a series of text–entry boxes. Three operating modes are available: 16–bit and 32–bit fixed–point, and 80–bit floating–point using the 68881. The help file states that the 80–bit mode will yield higher magnification (as it should)—but I was unable to make the program exceed the 32–bit fixed–point limit of 8 million diameters.

The File menu includes 'Save' and 'Load' items—but on the version of MEGABROT I have these items are not implemented. There is, however, a routine which will save the coordinates and magnification of a region of interest, allowing it to be recalculated from a list of region names.

There are three options for colors: gray–scale, rainbow, and random. 'Random' assigns random colors to dwells—the results are, to my taste, unattractive in the extreme. The color changing routine is excellent: one can select a range of color (along a color bar shown beneath the image) and then use the Color Picker to set the beginning and ending colors for that range, and the program then interpolates a smooth gradation of colors for the intermediate values of dwell.

The real and imaginary center coordinates, magnification, and maximum dwell are displayed to the right of the plotting window, along with a scrolling list of region names (saved parameters).

Finally, there are two options for mapping the colors onto the dwell values. 'Compress Within Range' takes the 63 colors and applies them to the actual range of dwells contained in the image, using one color for more than one dwell when the dwell range exceeds 63. 'Fold Over' maps the colors onto the dwells modulo 63, so the colors will repeat if the dwell range exceeds 63.

Mandelbrot Microscope

This is another program that plots in a 400x400–pixel fixed window. Selection is by dragging only—a menu item for 'Keyboard entry' brings up a print spooler error dialog box in this version. To the right of the plotting area is a vertical palette showing the color or grey scale being used, which is numbered from top to bottom with dwell values. (This numbering is actually reversed from the color–to–dwell relation in the image, since the palette runs from red to violet as dwells increase while the image starts with violet far from the Set and goes to red close to the Set.) The documentation points out that the correspondence between the palette and the image holds only for maximum dwells less than 256—above that the image colors are modulo 256 and will repeat the violet–red sequence.

The program claims to have a Save routine, and there is a Save item on the file menu which ostensibly saves files—but I was unable to open these files (receiving a 'disk error' message each time I tried), and hung the machine trying to drag them to the Trash Can. I cannot state that Save would not work on another Mac II, since I might have been getting interference from some Init file, but on my machine as currently configured I cannot save files from this version of MANDELBROT MICROSCOPE.

There are several options for displaying the image: a 256–shade grey scale, two different 254–color CLUTs, the ImageWriter colors, and a 6–step ImageWriter grey scale. Individual dwells can have their colors set with the Color Picker, and a range of colors may be set to a single color. A color palette, once tuned to your satisfaction, can be saved and reloaded.

Coordinates are reported at the upper and lower left and lower right corners of the plotting area, showing the maximum and minimum real and imaginary values for the region displayed, and also the distance in the complex plane between adjacent pixels. When working on the real axis, the correspondence between the vertical position of the image and the displayed imaginary coordinates breaks down at about 10 quadrillion diameters magnification (before truncation sets in). Working off the real axis, truncation can set in around 200 trillion diameters. (This dependence of maximum magnification on distance from the real axis could be shown only because of the pixel–distance reporting feature that is unique to this program.)

The plotting area has scroll bars, so small changes of position may be made by scrolling (and then waiting for recalculation).

Ani–Mandel

This is one of the most powerful programs in terms of magnification, but suffers from a very non-Maccish interface. With a few improvements in the selection procedure, this would be a very useful program for anyone interested in working at extreme magnifications..

ANI–MANDEL supports CLUT animation (as does MANDELCOLOR), and in this program the animation can be reversed, stopped in place, and single-stepped forwards and backwards. This useful feature gives you a large amount of control over the appearance of your screens. In addition, individual colors in the CLUT can be altered with the Color Picker.

The largest usable magnification is about 30 quadrillion diameters. Higher magnifications are possible, but truncation errors begin to produce an increasingly 'blocky' appearance beyond that point. There is no hard limit to the maximum dwell, so dwells of 4000 or so are quite possible. Extreme dwell values (as: 90,000) can be entered, but may not function as expected due to truncation errors. Nor would anyone want to wait while dwells that high were calculated.

The selection procedure is the worst aspect of the program. First of all, selection is done *only* by entering coordinates in a dialog box. An Option–click on a point in a plot will post the coordinates of that point to the upper left corner of the screen, where they will remain when the dialog box is opened, but there are two major flaws in this otherwise reasonable procedure: 1) the user has to *type* the coordinates into the dialog box (they should be automatically posted), and 2) the coordinates are shown to 9 digits only, and the text-entry fields display only 9 digits. Locating a plot at 30 quadrillion diameters can take up to 19 digits! Experimentation showed that it *is* possible to enter 19 digits into the text-entry fields, and the program will then utilize those figures—but the next time you bring up the dialog box your figures are all rounded off to 9 digits, and thus any figures beyond the ninth have to be re-entered *each* time the dialog box is brought up. Also, a lot of plotting and re–plotting is required to work up to high magnifications and keep track of precisely where you are.

The program always plots to the full screen (no multiple–window capability), and the colors are attractive. No saving of screens is possible, except with some external utility like Colorizer (but I found that the smoothness of the progression of colors was degraded in an image saved with Colorizer).

Finally, ANI–MANDEL also plots the Julia Set, which is something none of the other programs do. A rather simple modification to a Mandelbrot program will allow it to also plot the Julia Set, and it is surprising that only one of these seven programs has this useful addition. The Julia plot has access to all the features of the Mandelbrot plots: animation, full range of magnification, etc. The 'seed' value for the Julia plot may lie anywhere in or around the Mandelbrot Set, and the center of the viewing area may then be set anywhere in the plane of the Julia Set.

Considering all of its capabilities, this program is potentially one of the better Mandelbrot programs for the Mac II. If the author decides to give it a better selection method (or even allow the text–entry boxes to display 19 digits), and can make it save images, it would definitely be one of my preferred programs. I have talked to the author about the interface, and he has expressed interest in trying the following improvements:

1. Display all coordinates to the full 19 or 20 digits needed to work at high magnification.
2. Automatic posting of the coordinates of the clicked–on pixel to the text entry boxes.
3. Display of a rectangle around the clicked pixel showing the boundary of the next plot.

He was also amenable to the idea of letting the user set the escape radius.

MandelZot

MANDELZOT 0.9 is the first Macintosh II color Mandelbrot program (that I have seen) that makes use of the Mariani/Silver 'DivCon' computing algorithm to speed up the calculations, and also allows the user to set the escape radius to any value from 2 up. (Note that version 0.5 did not even make direct use of the 68881 and was thus *much* slower than the current version.) It should also be noted that this program will run on non–color Macintoshes.

Selection is by dragging, and aspect ratio distortion has to be watched for (as in MANDEL8) since the plotting is done in growable Macintosh windows (without scrolling capability). Multiple windows can be displayed.

There are four plotting options. Default is a pseudo–random plot, where the image fills in randomly all over the plotting window—an option which can give the user a guess at the appearance of a plot long before it is finished. Other options are Raster–scan (pixel by pixel along each horizontal line), and Line–at–a–time (somewhat faster, displaying each line after it has been calculated). The fourth option is the 'DivCon' algorithm, which checks the boundary of rectangular subregions and colors the interior of any region with a uniformly colored boundary to the same color as the boundary. This algorithm may produce some errors, since the boundary is checked only at finite intervals—but the speed is increased materially, and a region of interest may always be re–plotted in Raster–scan for maximum accuracy.

There are also four display options: monochrome (B&W) bands, grey–scale patterns, 8–color 'Old QuickDraw', and Color QuickDraw. Color QuickDraw is supposed to yield 56 colors (plus black and white), but the author informed me he had omitted a factor of four in the source code, and the present version will put up only 14 different colors in this mode.

Four calculation methods are possible: 16–bit and 32–bit fixed–point, 80–bit floating–point via SANE (these available on all systems), and 68881 80–bit floating point on a Macintosh II. In the 80–bit floating–point modes only, the escape radius may be set to any value from 2 up. This is the *only* Macintosh II color Mandelbrot program which gives the user a full choice of escape radius.

Coordinate reporting is done by posting the real/imaginary coordinates of the cursor (and the dwell) to the scrollbar region at the bottom of the window. The coordinates are listed to 18 decimal places (or even more if very close to zero)—which is almost enough to handle the full 30 quadrillion diameter magnification range of the program.

Images may be saved in three forms: coordinates and mode only (a small file, but the entire window must be recomputed), coordinates and mode plus a bitmap of all points within the Set (a larger file, but only points outside the Set need be recomputed), and a coordinates and mode plus full dwell data for all points (file size up to 500K, no recomputing unless the image was not completed when saved). None of these files are the usual color screen saves, so they cannot be used by other programs.

MANDELZOT will run in background mode under MultiFinder, although the 'DivCon' algorithm cannot be used in background.

The main defect of MANDELZOT at present is the small number of colors available, and the rather unattractive appearance of those colors. I have talked to the author, and was told that a much improved color–handling routine is in the works, providing more colors, more attractive displays, and means for altering the color setup. The 18–place limit on coordinate reporting appears to be a limitation of LightSpeed C, but some way around it may be found. Color animation is planned, and the ability to accept typed coordinates. Extension to other fractal sets is planned as well.

Mandelbrot 2.7

MANDELBROT 2.7 is in many ways the most professional–looking Mandelbrot program I have seen for the Macintosh II. The author devoted a great deal of thought and time to the user interface, especially as regards controlling the colors in the image, and has come up with a delightful product. If someone whose main interest was not photographing the screen had to be restricted to just one color Mandelbrot program, I would recommend this as the preferred program.

This program plots to a 450x450–pixel fixed window, so it cannot utilize large screens and will not provide as good resolution for photography as full–screen programs. For visual use on a standard color monitor the display is fine. To the right of the display is a control panel whose functions (many of them duplicates of menu items) allow one to operate most aspects of the program without referring to menus. An excellent on–line help file (in color) explains the operation of the program.

Selection is done by dragging or by typing in parameters—the coordinates of the lower left corner and the length of the sides of the square. Coordinate display is to 10 places only—not enough for the 30 quadrillion diameter magnification limit. Coordinates may be entered to a few more places than they are displayed.

Resolution may be set from 1x1 pixel to 15x15 pixels, which allows you to speed up plotting at the cost of resolution (an effect similar to using a smaller plotting window in some other programs).

Images may be saved and opened as working files, or saved as B&W PICT files. If the maximum dwell is increased, the current image will immediately be recalculated for the higher dwell—but only those parts of the image lying within the Set (as shown in the current image) will be calculated, speeding up the process considerably.

A 'Preferences' menu item lets you set defaults for the file loaded at startup, the size of the scrolling step, how color values are displayed, and whether the image should be displayed as it plots or only after plotting is complete.

The unique power of MANDELBROT 2.7, however, lies in its control over colors. At the bottom of the control panel is a 32x32 grid of 1024 little squares, one for each possible dwell value. These squares will show the actual color assigned to each dwell. Tools allow you to mark on the grid the range of dwells used in the current image, and then select any subrange (or individual dwell) to be colored. A subrange may be set to any color with the Color Picker, or may have its endpoints set to two different colors and a smooth interpolation made (either for Hue/Saturation/Brightness or for Red/Green/Blue). Subranges may also be set to random colors, but I did not find that to be very useful. I was able to set up close approaches to both the 'smooth' and contrast' CLUTS of MANDELCOLOR by utilizing the control panel facilities in MANDELBROT 2.7, and many other color patterns as well. A color palette may be saved, and may be loaded into any displayed image (which instantly reflects the new palette).

A so–called 'differentiation' routine controls the assignment of 254 colors to up to 1024 dwell values. Apparently the Palette Manager is being bypassed, so expect some rather odd things to happen to any desktop colors you have set. I use the 'Klutz' DA to restore the standard palette after I exit this program (and some of the other Mandelbrot progams as well).

Again, I have talked to the author, and improvements are planned. He agrees that a variable escape radius would be useful, and that coordinate entry and display should be capable of taking the 19 to 20 places required to match the maximum magnification of the program. A full–screen capability (to aid photography, and to handle large screens) may be added. Julia Set capability is planned, and color animation, as well as MultiFinder compatibility. Future versions of this program should be worth waiting for!

{This review will finish in the next issue with a table showing the main features of all seven programs, for rapid comparison, and a detailed discussion of their features.}

LETTERS

From: The Rev. G.A.G. Bennett (October 11, 1986)

... I use a computer manufactured by Acorn, called the "BBC B". It uses the 6502 microprocessor, an 8-bit unit, working at a speed of 2 MHz. The basic internal arithmetic functions on 4-byte numbers; and I soon found that this 32-bit arithmetic was insufficiently accurate at the extreme top (and bottom) of the Mandelbrot set and produced obvious distortions. Also it was insufferably slow. So I put together some machine code to function on 40-bit or 48-bit arithmetic, and made all arithmetic operations take place in zero-page of the memory (where operations are shorter). This was of bearable speed: 8 seconds to establish a point as being "in the set" on 48-bits (1024 iterations), and just over 6 seconds on 40-bits. With this I can map the Mandelbrot set at almost any desired resolution, though even then it can take 4 or 5 hours to derive a screenful in a not particularly 'black region'.

However, I also turned my attention to endeavouring to plot the outline of "the set", and have put together a programme, which I call "Mandleworm". This worms its way along the boundary of the "set" at any desired degree of resolution. Starting at the extreme left at the point (-2,0), the 'worm' moves first right, and then keeps trying to turn left; if this moves the test point outside the "set", it comes back, veers right and tries again. In this way the worm moves from point to point along the boundary of the "set", and generates a file containing a string of the four letters R, L, U, and D that describes the boundary at this degree of definition. Quite simple programmes in BASIC can then use this file to draw in detail the outline of the "set" in any required region.

The algorithm for Mandleworm is beautifully simple. I use three subroutines:

1) XSTEP, which adds the increment I onto the X coordinate; I is the size of the basic worm move selected.
2) YSTEP, which adds I onto the Y coordinate.
3) MANDL, which tests whether the point (X,Y) is in the set or not.

The algorithm starts with X=-2, Y=0, and is repeated continually until Y becomes negative. This traces the top half of the "set"; the bottom half is of course its mirror image. The algorithm is:

```
REPEAT:
XSTEP:   if not in "set" change sign of I, XSTEP
         if in "set" print "R" for I positive, else print "L"
YSTEP:   if Y goes negative, FINISH
MANDL:   if not in "set" change sign of I, YSTEP
         if in "set" print "U" for I positive, else print "D"
Change sign of I: and go back to XSTEP.
```

All this can be realised in about 75 bytes of machine code, though the three subroutines are much more extensive!

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From Jim Calkin (March 19, 1987):

... Upon reading [the August, 1985 Scientific American] on a business trip (about the only time I get to read the S.A.), I immediately set about to program the set on my Sperry (IBM compatible) PC at home. After reproducing the basic image and focusing or zooming in on some areas I started to explore other formuli than $z = z^2+c$ such as $z = z^3+c$, $z = z^4+c$, $z = z^5+c$, $z = z^6+c$. As my PC only has BASIC & does not handle complex numbers I had to do the arithmetic or algebra in real & imaginary parts. Upon examining the equations used it became obvious that what one was doing was handling the X and Y directions individually, without regard to the equivalence to complex manipulations. Therefore I sought to replace the key parts of the algorithm... with other functions: sines, cosines, tangents, square roots, etc in many combinations.

My eleven year old son Jeff found no little interest in what I was doing and contributed greatly to enhancements to the program to things like: Which of the 40 formulas to use this time, how to specify the center, edges and scale of the display, whether to paint it top down, bottom up, spiral out or spiral in, what colors and coloring scheme to use, how to specify & paint the LAND, LAKE & ISLAND portions of a drawing (the land is the part having colored bands that are distinguishable. The lake is the part that if colored normally looks like colored sand all mixed up & so if only one color is used for that part the ISLAND (BLACK part in S.A.) stands out better).

We began cranking out screens & printed copies thereof continuously & profusely for several months. I also took a roll of pictures of the screen (you may have a free copy if you like) and got 2 copies of each printed.

I showed these off at work in SLC (Sperry now UNISYS) and found no little interest there (among a small handful of souls) who proceeded to convert the basic BASIC parts to C or Pascal.

Another fellow left Sperry and went to work for IOMEGA and I gave him my algorithm. He and his coworkers there, who are into high speed stuff, speeded up the process a hundredfold or so over what I could do at home.

Our programs at home went thru the standard evolutionary trail of learning & trial & error. We tried putting up CHARACTERS in 16 colors on the screen, and then 7 background colors with a character in the foreground designating how many iterations that particular spot took (still 25 x 80[1]). Then my boy showed me how to do the pixel (200 x 320[2]) stuff (he had played with it previously) & so we converted to that better scale. One picture took 36 hours to generate. Then a friend gave me a compiler which speeded things up by a factor of 6 or 7. Now we can crank out a picture with a step size of 10^7 or so in from 5 to 12 hours, depending on the complexity of the arithmetic involved.

I must say that, of all the pictures (hundreds of them) I have, the original Mandlebrot ($z = z^2+c$) is like a castle in the midst of the fairytale forest while all of my other formulations are like peasants' cottages in the woods.

Perhaps you would be interested in my program or copies of some of the printouts. Many of the pictures I have generated prove the SELF-SIMILARITY principle on to infinitum, but others show none of it at all. I have found polygonal spirals, snaky spirals, repetitive patterns, etc.

We have experimented with variations in the maximum number of iterations to use to get a picture, the max. radius (always 2 in the SA article) and on & on...

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[1] RS: Low resolution mode on the Apple II.

[2] High resolution mode.

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All slides submitted for use in the Slide Supplement, or any other purpose, become the property of Amygdala. This policy is not retroactive, however, and I will return all slides submitted before now if I was asked to.

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